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Improving global scale land cover classifications with multi-directional POLDER data and a decision tree classifier

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Abstract

Several investigations indicate that the Bidirectional Reflectance Distribution Function (BRDF) contains information that can be used to complement spectral information for improved land cover classification accuracies. Prior studies on the addition of BRDF information to improve land cover classifications have been conducted primarily at local or regional scales. Thus, the potential benefits of adding BRDF information to improve *global* to continental scale land cover classification have not yet been explored. Here we examine the impact of multidirectional global scale data from the first Polarization and Directionality of Earth Reflectances (POLDER) spacecraft instrument flown on the Advanced Earth Observing Satellite (ADEOS-1) platform on overall classification accuracy and per-class accuracies for 15 land cover categories specified by the International Geosphere Biosphere Programme (IGBP).

A set of 36,648 global training pixels (7×6 km spatial resolution) was used with a decision tree classifier to evaluate the performance of classifying POLDER data with and without the inclusion of BRDF information. BRDF 'metrics' for the eight-month POLDER on ADEOS-1 archive (10/1996–06/1997) were developed that describe the temporal evolution of the BRDF as captured by a semi-empirical BRDF model. The concept of BRDF 'feature space' is introduced and used to explore and exploit the bidirectional information content. The C5.0 decision tree classifier was applied with a boosting option, with the temporal metrics for spectral albedo as input for a first test, and with spectral albedo and BRDF metrics for a second test. Results were evaluated against 20 random subsets of the training data.

Examination of the BRDF feature space indicates that coarse scale BRDF coefficients from POLDER provide information on land cover that is different from the spectral and temporal information of the imagery. The contribution of BRDF information to reducing classification errors is also demonstrated: the addition of BRDF metrics reduces the mean, overall classification error rates by 3.15% (from 18.1% to 14.95% error) with larger improvements for producer's accuracies of individual classes such as Grasslands (+8.71%), Urban areas (+8.02%), and Wetlands (+7.82%). User's accuracies for the Urban (+7.42%) and Evergreen Broadleaf Forest (+6.70%) classes are also increased. The methodology and results are widely applicable to current multidirectional satellite data from the Multi-angle Imaging Spectroradiometer (MISR), and to the next generation of POLDER-like multi-directional instruments.

Keywords: Global land cover; BRDF; Decision tree

1. Introduction

Land cover and land use are principal factors, in both space and time, controlling the cycling and exchange of carbon, energy and water within, and between, the different Earth systems. Thus, global land cover classifications are essential for a variety of diagnostic and predictive models that simulate the functioning of the Earth systems and are useful for investigating global change (Sellers et al., 1996; Townshend et al., 1994). Global land cover classifications also simplify the monitoring of natural or human-induced changes of land cover/use and are important in simulations of the *impact* of such changes on local and global processes (e.g. Bonan, 1997; Bounoua et al., 2002). In addition, coarse scale land cover classifications currently play an important role as ancillary data for various parameter retrieval algorithms using data from the *Terra* and *Aqua* satellite systems, and are expected to be used by several of the algorithms of the future National Polar

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Orbiting Environmental Satellite System (NPOESS) Preparatory Project (NPP) and the NPOESS operational satellite systems, to be launched later this decade and early next decade, respectively.

Global scale land cover classifications derived from Advanced Very High Resolution Radiometer (AVHRR) satellite data have achieved accuracies between 70% and 90% for up to 17 land cover types. Classifications using 8 km or coarser resolutions yield accuracies over 80% (DeFries et al., 1995, 1998; Friedl & Brodley 1997; Hansen et al., 1996), and those using 1 km resolution data yield accuracies near 70% (Hansen et al., 2000; Scepan, 1999). These classification accuracies in some cases have been determined from random samples of unseen test cases taken from samples used to train the classifier (DeFries et al., 1995, 1998; Friedl & Brodley, 1997; Hansen et al., 2000). Thus, actual accuracies can be expected to be lower when tested with independent validation data, as shown by Friedl et al. (2000). The correct typing probability for the 1 km IGBP-DIScover global land cover classification of Loveland and Belward (1997), checked against such an independent validation data set, was expected to reach 85%, but is in fact 67% (Scepan, 1999). The land cover product from the MODerate Resolution Imaging Spectroradiometer (MODIS) (Friedl et al., 2002; Strahler et al., 1999) is expected to have an accuracy near 80%.

The limitations to achieving higher classification accuracies discussed by DeFries et al. (1998), Loveland et al. (1999), and Hansen et al. (2000), emphasize data quality of the input data and the number and nature of the land cover classes of interest. Artifacts of data processing, substantial radiometric noise, geolocation errors, and the limited spectral coverage of systems such as AVHRR inhibit the ability to separate spectrally similar land cover classes. Many land cover types, especially at coarse spatial scales, show as much intra-class variability as inter-class spectral variability. This variability frequently exhibits multimodal distributions that cause serious difficulties for traditional classifiers such as Maximum Likelihood Classifiers (MLC). New non-parametric classifiers such as decision trees are preferred to parametric classifiers for coarse resolution applications because these do not assume normally distributed input data, as a MLC does (Friedl & Brodley, 1997; Hansen et al., 1996).

Improved classifications should also result from improved processing of the input data such as atmospheric corrections and may also benefit from mitigation of the non-Lambertian behavior of terrestrial surfaces. The data currently available from sensors such as MODIS, and the Visible/Infrared Imager/Radiometer Suite (VIIRS) to be flown onboard NPP and NPOESS, incorporate such corrections and (will) have significantly superior radiometric performance and stability. Additional spectral bands, particularly in the middle infrared portion of the spectrum, and improved geolocation are also expected to substantially benefit land cover classification algorithms and any derived products.

Principal sources of confusion for global scale classifications are usually absent between large 'core' classes such as forest and bare/sparsely vegetated (e.g. DeFries et al., 1998; Han et al., 2004; Hansen & Reed, 2000). Confusion typically occurs between surfaces that are similar spectrally and temporally, such as different forest types (e.g. Deciduous Broadleaf Forest and Mixed Forest), Wooded Grasslands and Woodlands, Open and Closed Shrublands, and/or Grasslands and Croplands. In addition, other classes such as Urban areas and Wetlands are poorly characterized from visible/infrared satellite data (Han et al., 2004; Scepan, 1999).

5. Conclusions

The analyses conducted here indicate that the POLDER instrument provides the data required to study coarse BRDF patterns at the continental to global scales. Because of its unique sampling geometry, it is able to capture elements of the surface BRDF that are simply not available from cross-track scanners such as the AVHRR. The data from POLDER are also able to capture the broad features of the BRDF in multiple spectral bands and over time. Further, the eight-month archive of POLDER data is sufficient to allow the utilization of these seasonal BRDF patterns for the study of land cover.

The use of semi-empirical BRDF models (Roujean et al., 1992) with POLDER data allows the salient features of the surface BRDF for most cover types to be adequately described in an efficient manner, while retaining a physical meaning in most cases. The coefficients of the Roujean et al. (1992) model are able to describe the general importance of geometric and volumetric scattering effects for many cover types, with the broad patterns seen here concurring with patterns seen in field data and other global POLDER analyses (Bicheron & Leroy, 2000; Roujean et al., 1992). It is evident from the data analyzed here that the volumetric component of the BRDF is much more important than the geometric component for all cover types at this spatial scale. At the spatial scale of several kilometers of the POLDER global data, it is possible that the geometric structure of many canopies, such as trees and shrubs, and the shadowing that these features introduce, is much less important, and that the surface is much more of a turbid medium than at a finer scale. The broad variations seen in the k_1 coefficient indicate that, even at this spatial scale, some information about the surface structure is still present.

The production of BRDF metrics from the POLDER data allows an investigation of the potential land cover specific information of the BRDF. This research finds that the patterns described by these metrics, even with a large amount of overlap between most classes, still contain information that is useful for land cover discrimination. By examining the feature space of the different BRDF metrics this information can be determined qualitatively. These 'coefficient feature space' plots indicate that the coarse scale BRDF coefficients from POLDER provide land cover information that is different from the spectral and temporal information, and is useful for land cover separation. Whether this information is actually completely independent from the spectral and temporal information is not yet known. Moreover, the actual independence of all the BRDF metrics from each other is an issue that merits further attention both in terms of potential data reduction but also future improvements.